# The AIRSAR Polarimetric Interferometry Calibration

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## ABSTRACT

In this paper, The polarimetric interferometry mode data is calibrated in two steps. The first one is the interferometric calibration with double baseline operation mode for each pair polarimetric data channels. The second step is the radiometric calibration for the polarimetric stokes matrix channels. The initial results are very promising and potential applications of polarimetric interferometry can be verified by comparing polarimetric interferometry signatures with ground truth data. The choice of a homogeneous calibration site is a crucial element for studying vegetation classification using polarimetric interferometry data . We present several polarimetric interferometry data sets to demonstrate this calibration processing.

## INTRODUCTION

The NASA/JPL TOPSAR system was modified to collect polarimetric interferometry data at C-band. The first experimental cross-track interferometric data collection was conducted in 1998 by collecting polarimetric data for both upper and lower antennas. Polarimetric interferometry combines both SAR polarimetry and SAR interferometry. The polarimetric response is highly sensitive to the scattering mechanisms within a pixel while SAR interferometry is sensitive to the location of a pixel and its scattering geometry. we present the calibration techniques for NASA/JPL polarimetric interferometry data processed with the AIRSAR Integrated Processor (AIP). The AIP is an integrated multi-frequency polarimetric and interferometric SAR processor . The processor is utilized to automatically generate co-registered multi-frequency (C-,L-,and P-band) images for all 12 data channels which are projected and terrain-corrected onto the DEM generated by any single pair of interferometric channels.

Calibration of polarimetric radar system is one of the fields of research in which great progress has been made over the last few years. [1]. To fully calibrate the SAR data, a number of corner reflectors external calibration devices must be deployed prior to imaging. These corner reflectors serve to provide the absolute radiometric calibration and the VV polarimeritc data relative to the HH polarimetric data. The phase calibration and cross-talk removal has been established as well [2]. Interferometric measurements are obtained from subtle phase signatures shown in two SAR images. Therefore , two images must be co-registration. The correlation of two SAR images depends on various parameters such as SNR (Signal Noise Ratio), the pixel scattering decorrelation, geometric decorrelation and the temporal decorrelation. The differential time delay between two images is calibrated first. Then the two antennas base-line and differential phase will be calibrated associated the ground truth information. The Polarimetric interferometry can be implemented by collecting polarimetric data for both upper and lower antennas. The same polarization interfometry data can be used to derive DEMs and decorrelation amount associated with each polarization. The phase center and correlation coefficient of each polarization response may be used to retrieve physical scattering features such as the tree height. The usefulness of these data sets must be evaluated by comparing them with the ground truth data.

## POLARIMETRIC SAR CALIBRATION

Due to the path length differences among the four polarization combinations, HH, HV, VH, and VV in the radar hardware, a model had been developed [4] to identify the receiver path phase ($\Phi r$), transmitter path phase ($\Phi t$) and antenna path phase ($\Phi a$). Above three path phases measurements can be obtained from the SAR data with co-polarization and cross-polarization phases and injected caltone phase($\Phi$cal), which are $\Phi r = \Phi cal$, $\Phi t = \Phi hv^* vh + \Phi cal$, and $\Phi a = (\Phi hhvv - \Phi t - \Phi r)/2$. The cross-talk error is due to imperfections in the radar antenna resulting in impure polarization states for the individual polarization combinations measured directly by the hardware. We can get a better estimate of the cross-talk parameters at a given range if we use the average of all the estimates over an entire range line[4]. We have implemented this by using eight adjacent pixels in each range line to get one estimate of the cross-talk parameters then average over the estimates of all the eight pixel blocks fo r each range line. What remains is to utilize the backscatter measurements from corner reflectors to correct the residual amplitude offsets in the various polarization channels and to correct for the absolute gain and co-polarized component phase of the radar system. In calculating the correlator gain, we use the theoretical expression for triangular trihedral corner reflector cross-section found in Ruck et al.:

$$\sigma = \frac{4\pi}{\lambda^2} l^4 \{\cos\theta + \sin\theta(\sin\phi + \cos\phi) - [\cos\theta + \sin\theta(\sin\phi + \cos\phi)]^{-1}\}^2$$

Where $l$ is the length of corner reflector sides , $\lambda$ is the radar wavelength, $\theta$ is radar wave incident angle, and $\phi$ is corner reflector azimuth angle. The data is absolutely calibrated to within 3dB and relatively calibrated to be better than 1 dB.

## INTERFEROMETRIC SAR CALIBRATION

The polarimetric interferometry upper and lower antennas are separated by 2.5 meter with a roll angle of 50 ° and a baseline yaw angle of –0.5°. The basic equations describing interferometric synthetic aperture radar performance are well known[4]. In our calibration of the interferometric SAR data, we determine the following parameters: time delay, the physical baseline length , baseline roll and yaw angles, the differential phase, and phase screen. In practice, the determination of the time delay is divided up into determining the differential time delay between pairs of upper and lower data channels processed interferometrically and determining a common range delay. The motion attitude yaw and pitch angle biases for the embedded GPS/INS are determined in an earlier calibration stage. The calibration parameters are determined by fitting the errors in the imaged corner reflector positions using the known sensitivity of the target position to calibration parameter errors. Given airplane position **P** vector, line of sight **n** vector and slant range $\rho$, the position vector to the resolution cell, **T** vector, can be obtained by means of the equation: $\mathbf{T} = \mathbf{P} + \rho \cdot \mathbf{n}$ . The error in the interferometric measurement can be written as

$$\delta T = \delta P + \rho \cdot \delta n + \delta \rho \cdot n \qquad (1)$$

The interferometric phase is given as $\delta\varphi = (-4\pi/\lambda)[(\rho 1 - \rho 2)\cdot \mathbf{n}]$ , where $\rho 1$ and $\rho 2$ are slant range from upper and lower antennas , respectively. The length of baseline is $\delta\rho = \rho 1 - \rho 2$ and can be expressed as $\delta\rho = -B \sin(\theta - \alpha)$ and the interferometric phase can be expressed as below::

$$\delta\phi = (4\pi / \lambda) \cdot B \cdot \sin(\theta - \alpha) \qquad (2)$$

The DEM is calculated as $Z(y) = h - \rho \cos(\theta)$ and $\theta$ can be derived from equation (2).

For the interferometric phase, we derive the baseline vector and differential phase by using the flat portion of the Rosamond lakebed with 663 meter site height in the WGS-84 projection. When a common flight track is used for processing both interferometric channels, the interferometric phase $\delta\phi$ can be written as

$$\delta\phi = (-4\pi / \lambda) \cdot (\hat{n}_t - \hat{n}_r) \cdot \overline{B}_t - \frac{4\pi}{\lambda} \hat{n}_r \cdot \overline{b} + \Delta\phi + 2\pi m + \phi_e \qquad (3)$$

where $\lambda$=wave length, nr=true unit look vector, nr=reference unit look vector, Bt=true baseline vector,b=baseline error vector,$\Delta\phi$=differential phase, M=absolute phase number, and $\phi e$=phase due to earth curvature.

When the reference flat height is the same as the ture height, the first term of (3) becomes zero. Then, we made an earth curvature corrections. After the correction phase ambiguity number m is determine, the resulting phase $\phi c$ can be written as

$$\phi_c = \delta\phi - \phi_e = -\frac{4\pi}{\lambda}\hat{n}_r \cdot \bar{b} + \Delta\phi \qquad (4)$$

Using the interferometric data, we can determine the baseline error vector (b) and differential phase($\Delta\phi$) with a least square error technique.

## POLARIMETRIC INTERFEROMTRY

The data product of the interferometry by using the linear polarization basis are summarized in the Table 1. Various coherent scattering vector representations can also be used to obtain the cross correlation coefficient that enhances the desired scattering property. Two stokes matrix polarimetric are formed by upper and lower anttenas HH,HV,VH,and VV respectively.

| Upper/ Lower | S-hh* | S-hv* | S-vv* |
|---|---|---|---|
| S-hh | HH interferometry | S-hh S-hv* | S-hh S-vv* |
| S-hv | S-hv S-hh* | HV interferometry | S-hv S-vv* |
| S-vv | S-vv S-hh* | S-vv S-hv* | VV interferometry |

Tsblr 1. Polarimetric Interferometry Data Products

It is expected that each pixel can be characterized better by using both SAR polarimetry and SAR interferometry. The phase center and correlation coefficient of each polarization response may be used to retrieve physical scattering features such as the tree height. The usefulness of these data sets must be evaluated by comparing them with the ground truth data. For the Ontario data set, the results are very promising. For a combined error of the aircraft and site altitude locations, we assume 10 meters. The look vector error is approximately 0.001 for a slant range of 10 km. The average height error is about 5 meters.

## CONCLUSIONS

In this paper, we presented the key elements of calibrations for polarimetric interferometry data. In order to use SAR data for science applications, desired geophysical parameters must be measurable when SAR data are properly enhanced. The relationship between SAR data and geophysical parameters can be obtained by both theoretical and empirical approaches. We present several polarimetric interferometry data sets to demonstrate these calibration processing.

## REFERENCES

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